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Fractomechanoluminescence Produced During Impulsive Deformation of X and Γ-Irradiated Alkali Halide Crystals

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ABSTRACT

During impulsive deformation of X and γ irradiated alkali halide crystal two peaks are observed in the ML intensity versus time curve. The peak ML intensity I_{m1} and I_{m2} increases with the impact velocity v_0, however the time t_{m1} and t_{m2} decreases with the increasing impact velocity of the crystal. The slope of lnI versus (t-t_{m1}) plot decreases with increasing impact velocity v_0, however the slope of lnI versus (t-t_{m2}) plot is independent of impact velocity v_0. Therefore ML intensity I_T initially increases linearly and then it tends to attain a saturation value for higher value of v_0.

Keywords: Mechanoluminescence, Fractomechanoluminescence.

INTRODUCTION

In γ-irradiated alkali halide crystals, the following two processes may give rise to the light emission during their fracture: (i) The charged surfaces produced during fracture of certain alkali halide crystals may produce gas discharge ML, and (ii) the dislocations moving near the tip of cracks in the crystal may capture electrons from the F-centres and the electric field due to the newly created charged surfaces at fracture may release the dislocation captured electrons and subsequent electron-hole recombination may give rise to the light emission.

The coloured alkali halide crystals produce ML during their elastic deformation, plastic deformation and fracture (Chandra 1998, 2011). As the intensity of fracto ML is much more as compared to that of elastico ML and plastico ML, the elastico ML and plastico ML can be neglected as compared to the fracto ML.

Theory

The rate of creation of new surfaces is $\frac{dS}{dt}$ (Chandra *et.al* 2012) is given by

$$\frac{ds}{dt} = bZ_0V^{(m+m')}K_0(n+n'-n'')\frac{v_0}{H}\exp[-\{(\xi+\gamma)t\}]\left[\frac{v_0}{H\xi}\{1-\exp(-\xi t)\}\right]^{n+n'-n''-1} \quad (1)$$

where

b = a constant, Z_0 = proportionality constant, V = volume of crystals
m = an exponent, m' = an exponent, K_0 =a constant, n=an exponent
n' = an exponent, n'' = an exponent, v_0 = initial velocity of piston
H = thickness of the sample,
$\xi = \frac{1}{\tau_r}$ = rate-constant for the relaxation of moving piston
τ_r = time constant for the relaxation of moving piston
and γ = rate constant for the decrease of average surface area produced by the movement of single crack

Based on the detrapping of dislocation captured electrons by the electrostatic field produced by the charged dislocation, expressions are derived for the transient ML intensity I, rise of ML intensity I_r, ML intensity I_{m1} for the first peak, ML intensity I_{m2} for the second peak, time t_{m1} for the first peak, time t_{m2} for the second peak, temperature dependence of ML, colour centre density dependence of ML, crystal size dependence of ML, total ML intensity I_T, fast decay of ML intensity I_{df} and for the slow decay of ML intensity I_{ds}. A comparison made between the experimental and theoretical results indicates a good agreement. The expressions derived are given below

$$I = \eta_3^0 \beta n_d = \frac{\eta_3^0 \beta g_0}{\alpha'(\beta-\xi)}[\exp(-\xi t) - \exp(-\beta t)] \tag{2}$$

$$I_r^s = \frac{2 f_0 \eta_3^0 \beta \lambda r_F n_F N_d b Z_0 V K_0 v_0 \alpha_1}{H\alpha'} t \tag{3}$$

$$t_{m1}^s \approx \frac{1}{\beta} \ln \frac{[\beta H\{1-\exp(-\delta v_0)\}]}{v_0} \tag{4}$$

$$I_{m1}^s = \frac{2 f_0 \eta_3^0 \lambda n_F r_F N_d b Z_0 V K_0 v_0 p_F}{H} \tag{5}$$

$$I_d^s = I_m \exp[-\xi(t - t_m)] \tag{6}$$

$$I_{T1}^s = 2 f_0 \eta_3^0 \lambda r_F n_F N_d b Z_0 V K_0 p_F [1 - \exp(-\delta v_0)] \tag{7}$$

$$I = \eta_2^0 \chi N = \frac{2\lambda \eta_2^0 \chi f_0 f_0' r_F n_F b Z_0 V K_0 v_0 p_F}{H(\xi - \chi)} \left[\exp(-\chi t) - \exp(-\xi t)\right] \tag{8}$$

$$t_{m2}^s = \frac{1}{(\xi - \chi)} \ln\left(\frac{\xi}{\chi}\right) \tag{9}$$

$$I_{m2}^s = 2\lambda \eta_2^0 f_0 f_0' r_F n_F b Z_0 K_0 v_0 A p_F \tag{10}$$

$$I_{T2}^s = 2\lambda \eta_2^0 f_0 f_0' r_F n_F b Z_0 V K_0 p_F [1 - \exp(-\delta v_0)] \tag{11}$$

$$I_{d2}^{s} = I_{m2} \exp[-\chi(t - t_{m2})] \tag{12}$$

$$I_{m1}^{s} = \frac{2f_0\eta_3^0\lambda n_F r_F N_d b Z_0 V K_0 v_0}{H} p_F^0 \exp\left(-\frac{E_a}{KT}\right) \tag{13}$$

$$I_{m2}^{s} = \frac{2\lambda\eta_2^0 f_0 f_0' r_F n_F b Z_0 V K_0 v_0}{H} p_F^0 \exp\left(-\frac{E_a}{KT}\right) \tag{14}$$

$$I_{T1}^{s} = \frac{2f_0\eta_3^0\lambda r_F n_F N_d b Z_0 V K_0 v_0}{\xi H} p_F^0 \exp\left(-\frac{E_a}{KT}\right) \tag{15}$$

$$I_{T2}^{s} = \frac{2\lambda\eta_2^0 f_0 f_0' r_F n_F b Z_0 V K_0 v_0}{H\xi} p_F^0 \exp\left(-\frac{E_a}{KT}\right) \tag{16}$$

EXPERIMENTAL SUPPORT TO THE PROPOSED THEORY

Fig.1 shows the time dependence of the ML intensity of γ-irradiated KCl crystals, in which the crystals were fractured by the impact of a moving piston at different impact velocities. It is seen that initially the ML intensity increases with time, attains a peak value and then it decreases with time, and later on it again increases and attains a peak value again and later on it decreases with time. It is seen that the peak ML intensities I_{m1} and I_{m2} corresponding to the first and second peaks in the ML intensity versus time curve increase with the impact velocity v_0. It is also seen that the times t_{m1} and t_{m2} corresponding to the first and second peaks of ML intensity versus time curve decrease with the increasing impact velocity of the piston. These results follow Eqs. (2).

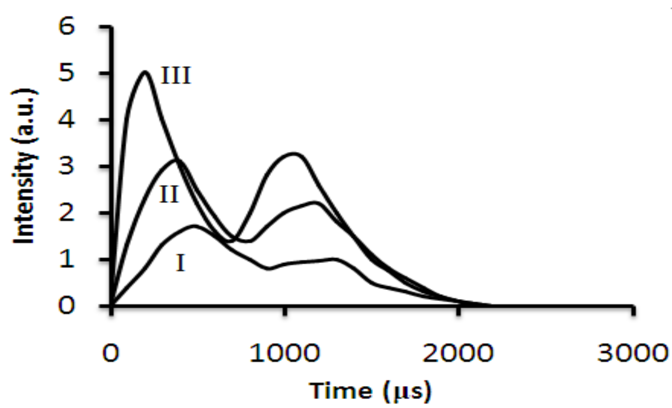

Fig. 1 **Time dependence of the ML intensity of γ-irradiated KCl crystals (Curves I, II and III correspond to the impact velocity 98.9, 197 and 280 cm/s, respectively. Size of crystals=2×2×2 mm) (after Chandra and Ramrakhaini 1992).**

Fig.2 illustrates the semilog plot of ML intensity versus (t-t_{m1}) for γ-irradiated KCl crystals. It is seen that the plots are straight lines with negative slops. This result follows Eq. (6). The values of ξ are found to increase with increasing impact velocity.

Fig.3 shows the semilog plot of ML intensity versus (t-t_{m2}) for γ-irradiated KCl crystals. It is seen that the plots are straight line with negative slops. This result is in accord with Eq. (12). It is seen that there is no significant change in the value of χ with increasing impact velocity v_0.

Fig.4 shows the dependence of I_{m1} and I_{m2} on the impact velocity v_0. It is seen that both I_{m1} and I_{m2} increase linearly with the impact velocity v_0. These results follow Eqs. (5) and (10).

Fig.5 shows the dependence of the total ML intensity I_T on the impact velocity v_0. It is seen that initially the ML intensity increases with the impact velocity and later on it tends to attain saturation value for the high impact velocity v_0. This result follows Eq. (7).

Fig.6 shows that the value of t_{m1} and t_{m2} decrease with increasing impact velocity of the piston. This result follows Eq. (4).

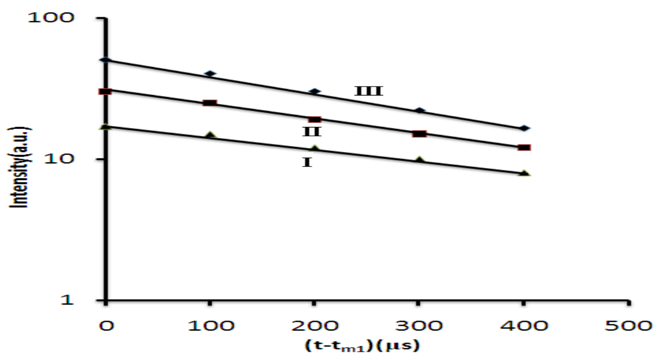

Fig. 2 Semilog plot of ML intensity versus (t-t_{m1}) for γ-irradiated KCl crystals (Curves I, II and III correspond to the impact velocity 98.9, 197 and 280 cm/s, respectively. Size of crystals=2×2×2 mm)

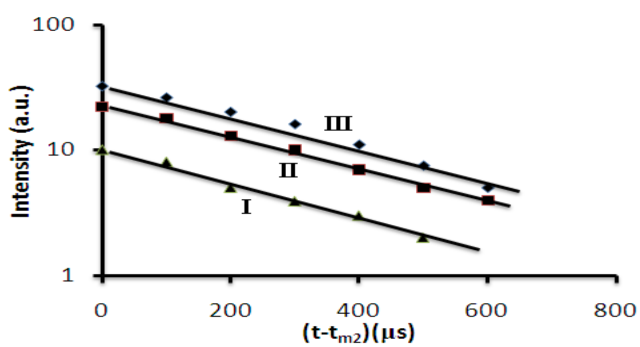

Fig. 3 Semilog plot of ML intensity versus (t-t_{m2}) for γ-irradiated KCl crystals (Curves I, II and III correspond to the impact velocity 98.9, 197 and 280 cm/s, respectively. Size of crystals=2×2×2 mm).

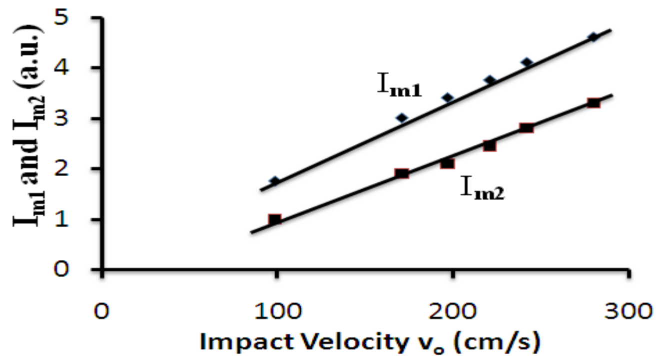

Fig. 4 Dependence of I_{m1} and I_{m2} on the impact velocity v_0 of the piston for γ-irradiated KCl crystals.

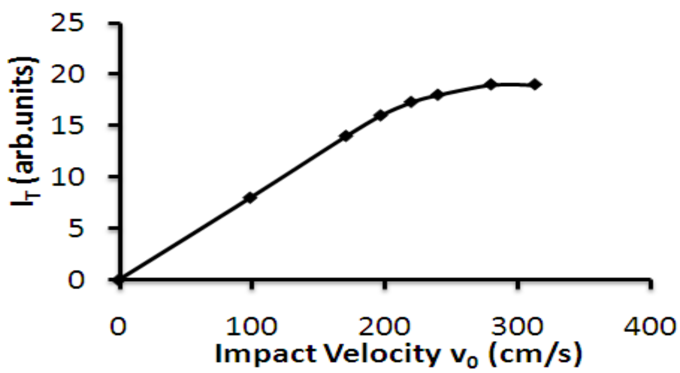

Fig. 5 Impact velocity dependence of the total ML intensity I_T for γ-irradiated KCl crystals (Optoelectronics Lab. RDVV, Jabalpur).

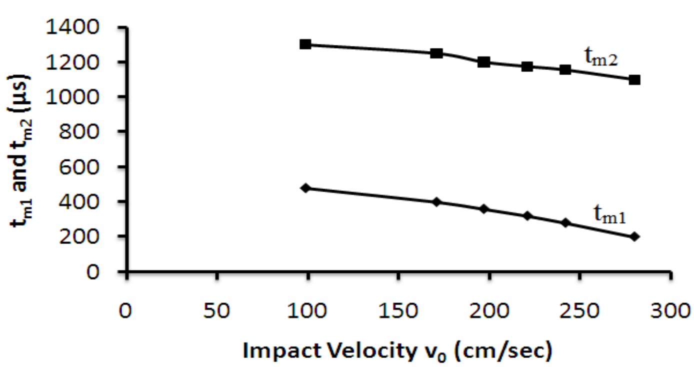

Fig. 6 Dependence of t_{m1} and t_{m2} on the impact velocity v_0 of the piston for γ-irradiated KCl crystals.

CONCLUSION

When a γ-irradiated KCl crystal is fractured impulsively by dropping a load from a given height, then initially the ML intensity increases with time, attains a peak value and then it decreases with time and later on it again increases and attains a peak value again and later on it decreases with time. Thus two peaks of intensities I_{m1} and I_{m2} at times t_{m1} and t_{m2} respectively are found in the ML intensity versus time curve of the crystals. A good agreement is found between the theoretical and experimental results.

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